Exploring aerosol optical depth: unveiling meteorological impacts over Lumbini, Nepal

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Abstract: Lumbini (27°29.387'N, 83°16.745'E), the birthplace of Gautam Buddha which lies in Indo Gangetic plain, having elevation of about 100m. The main source of aerosol is due to the biomass burning, large amount of running vehicles and due to the industries and factories situated nearby cities and also from transboundary pollutants. The Central Instrument Monitoring Equipment Lab (CIMEL) sun photometer recorded the value of Aerosol Optical Depth (AOD) at different wavelengths. This study is focused on the daily variation of AOD and its Angstrom exponent and turbidity coefficient with rainfall and relative humidity. The findings from the statistical analysis reveals that there is positive correlation in between AOD and heavy rainfall. However, the correlation between AOD and humidity was found to be negative. The similar type of relationship was obtained with angstrom exponent and turbidity coefficient. Not only rainfall and relative humidity but there are also other parameters (temperature, wind speed, human activities, etc.) having key role in the increment or decrement of aerosols. Due to the insufficient data, we could not perform study with such parameters.

Keywords: AOD; Meteorological parameters; Statistical tools; Correlation coefficient; Turbidity coefficient.

Introduction

The smallest particles that are moving freely in the atmosphere whose size vary from 0.01 to 10 microns are known as aerosols [1]. Aerosols may be solid or liquid. For example, dust and smoke are solid whereas haze droplets, fog, etc. are liquid aerosols. The majority of aerosols are composed of particles such as dust, carbon monoxide, and hydrocarbons. Aerosols are also produced by tires on cars, smoke from fireplaces, barbecues, large-scale agriculture (pesticide application), diesel engines, trains and aircraft. [2]. In our atmosphere aerosols are omnipresent and may be obtained from natural as well as anthropogenic sources. The important role of aerosols is that they can changes not only regional but also global climate either directly by scattering or absorbing solar radiation or by acting as cloud condensation nuclei [3]. There is also indirect effect of aerosols on cloud formation and precipitation, such as number and size of cloud droplets, making them more complex and uncertain [4]. Aerosols are ever-present in the atmosphere having direct effect on the earth's climate system and human health [5]. Due to the industrialization, urbanization and high population density the study of aerosols physical, chemical and optical properties study have increased sharply, as aerosols are responsible for the blockage of sunlight and scattering of solar radiation [6].

Aerosols are quite different from greenhouse gases in terms of climate change, since they scatter the solar radiation back into the space making the earth surface cooler [7].

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Gases present in the atmosphere and particulate matter gets mixed together to form aerosols in earth's atmosphere [8]. The imbalance in the radiation budget through direct, indirect and semi-direct effects shows the impact of aerosol on climate system [9].

Aerosol Optical Depth is the numerical assessment of amount of solar radiation blocked by dust and haze that may be either due to absorption or scattering of light. The information about how much solar energy is blocked by the aerosol's particles can be obtained from the AOD. It is the crucial variable for researching the characteristics of atmospheric aerosols and how they interact with direct solar radiation through the process of scattering and absorption. Thus, meteorological condition and altitude can alter it [10]. The amount of solar radiation that reaches the earth's atmosphere is lessened because of the scattering and absorption by aerosols, ozone layer and other atmospheric gases [11]. Also in the clear sky there is the domination by aerosols on the diminution of solar energy at visible and near-infrared wavelength ranges. Hence, AOD can be written as calculation of vertical direction of total integrated particle load in the atmosphere. It is a physical quantity with no dimension and evaluates the opacity of vertical column [12,13].

In physics, Optical depth or optical thickness is the natural logarithm of the ratio of incident to transmitted radiant power through a material; spectral optical thickness or spectral optical depth is the natural logarithm of the ratio of incident to transmitted spectral radiant power through a material. Optical depth specifically is not a length but a quantity with no dimension, which is a monotonically increasing function of optical route length and will be zero as path length becomes zero [14].

Mathematically,

$AOD_{550nm} = AOD_{500nm}(\frac{550}{500})^{-\alpha}$ ……………………….... (1)

Here in equation (1), the AOD measured at 500nm wavelength is denoted by AOD_{550nm}. In this case, α represents the Angstrom exponent from the 440-870 nm wavelength.

$\alpha = -\frac{ln\frac{\tau_1}{\tau_2}}{ln\frac{\lambda_1}{\lambda_2}}$ ……………………… (2) Where τ_1 and τ_2 are the AOD at wavelengths λ_1 and λ_2 [15].

Measuring site

Lumbini, the birthplace of Gautam Buddha which lies in Nepal and geographically it is northern part of Indo-Gangetic plain. The Indo-Gangetic plain covers a distance of over 2000km, spanning a large region in northern south Asia, including eastern Pakistan, much of eastern and northern India, southern Nepal, and nearly all of Bangladesh. The Himalayan Mountains and their foothills run along the northern border of the Indo-Gangetic plain. In the past decade, this area has experienced significant economic development, however, it has also become a highly polluted 'hotspot' of air pollution that is causing concern at the local, regional, and global levels [16]. Due to the rapid industrialization, urbanization, and high population density in this region, pollution levels are increasing and has serious impact on climate change, glaciology, and monsoon circulation [17]. The measuring site of the present study is given in figure1.

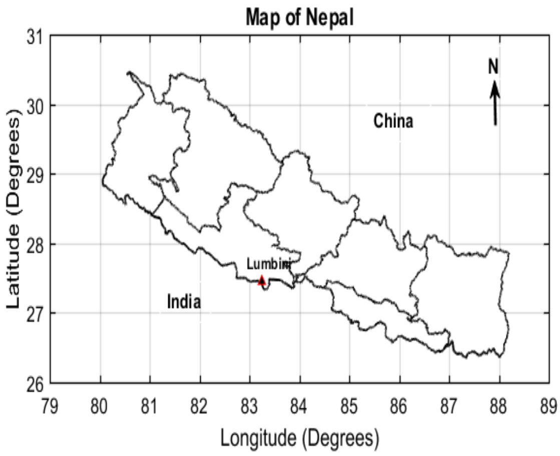

Figure 1: Measuring site of the Nepal [18].

The aerosol measuring instrument Cimel sunphotometer was installed by NASA Aerosol Robotic Network at the Lumbini International Research Institute (LIRI) (27°29.387'N, 83°16.745'E) having an elevation of about 100m above the sea level [19]. The annual rainfall of this area is about 1369.5mm and the maximum and minimum temperature of this region are 31.8°C and 18.7°C respectively [20].

Instrumentation and Methodology

The Aerosol Robotic Network (AERONET) is a federated ground-based instrument network measuring and characterizing aerosol properties including AOD. The standardized values for regional to global aerosol monitoring is done by global distribution of Cimel sun and sky scanning radiometers. For measuring direct sun, aureole and sky radiances, this radiometer has ~1.2° full angle field of view [21]. We can obtain AOD from direct sun measurements made in several spectral bands between 340 and 1640nm. We can draw out information about particle size distributions, how light scatters off these particles and their optical properties (refractive index) by observing radiance at various scattering angles [22].

The CSPHOT (CIMEL Sun Photometer) is an automatic radiometer that measures direct solar irradiance and sky radiance at the earth's surface using multiple channels by scanning the sun and sky. Measurements are conducted at specific wavelengths in the visible and near-IR spectrum to analyze atmospheric transmission and scattering characteristics. This device can withstand any weather conditions and needs minimal maintenance even for bad weather. Measurements are only taken during the hours of daylight. As per AERONET, the precision of aerosol optical thickness ranges from 0.01 to 0.02 when using field CIMEL instruments. Measurements of sky brightness have a precision of plus or minus 5% [23].

Results and Discussion

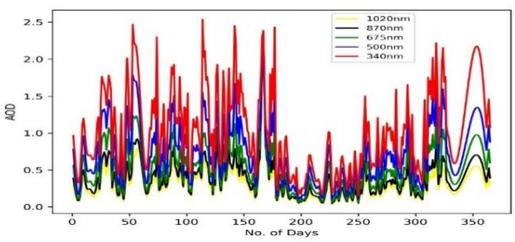

Figure 2: Variation of AOD for five different wavelengths for the year 2018.

Utilizing the methodologies and datasets previously mentioned, the AOD data for the location Lumbini in 2018 were examined. The angstrom exponent and turbidity coefficient were calculated by using above formula through python coding. Figure 2 shows the daily variation

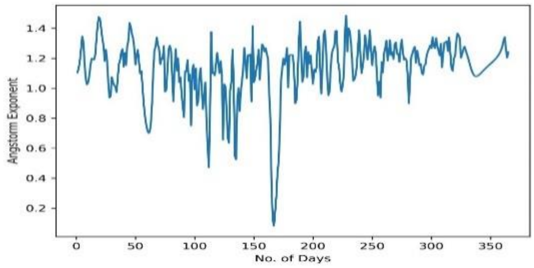

Figure 3: Variation of Angstrom exponent throughout the year 2018.

AOD of five different wavelengths of electromagnetic (EM) radiation. The EM radiation of 340nm (red color) has shown greater optical depth comparing to other wavelengths. The AOD measured by 340nm light has shown highest value of 2.538 and lowest value of 0.157, similarly the AOD measured by 1020nm wavelength light has the highest value 2.163 and lowest value 0.042. From the graph it is seen that the value of AOD was higher during the first six months and decreased for next four months and then again it raised. Figure 2 shows the daily variation of angstrom exponent of the year 2018. The highest value of angstrom exponent was 1.485 and lowest value 0.081 respectively. The value of Angstrom Exponent (α) ranges from 0 to 4 and its high value indicates high ratio of small to larger particles. If the size of aerosol is very small nearly of the size of air molecules, its value should be nearer to 4 and 0 for larger particles. A good average value for natural atmosphere is 1.3 ± 0.5. It was seen that there was steady decline in the month of June for 7-8 days which indicates the dominance of coarse-mode aerosols having effective radius greater than 0.5μm [24].

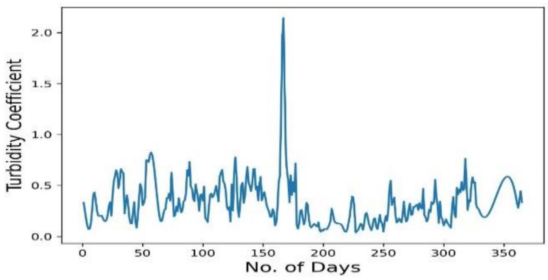

Figure 4: Daily variation of turbidity coefficient for 2018.

Figure 3 shows the day-to-day variation of turbidity coefficient of the place Lumbini of the year 2018. The highest value of turbidity coefficient was found to be 2.145 and lowest value 0.038 respectively. The value of β

typically lies between 0.0 to 0.5 or even higher represents the amount of aerosol present in the atmosphere in vertical direction [25].It is seen that there is sharp increase in the June month and rest of the year there is not so fluctuating curve which indicates the turbid condition i.e. high aerosol concentration and dryness [26].

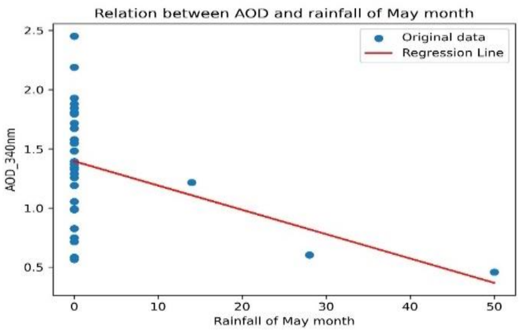

Figure 5: Correlation of AOD 340nm with rainfall of the may month.

Figure 4,5,6 and 7 shows the correlation of the AOD with rainfall of the months May, June, July and August. As per the Department of Hydrology and Meteorology (DHM) data there was no rainfall in the February, October, November and December months. There had been rainfall in January and March month only one day, September 2 days and April 4 days. In August, there was highest rainfall

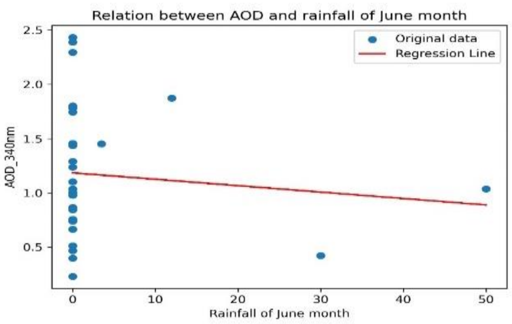

Figure 6: Correlation of AOD 340nm with rainfall of the June month.

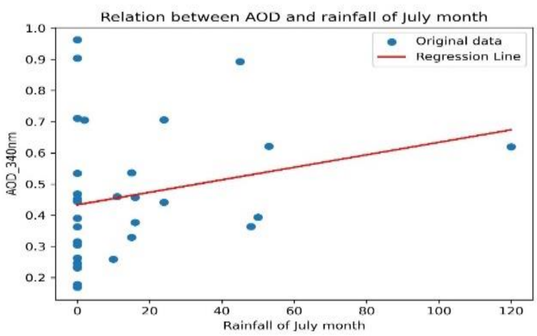

Figure 7: Correlation of AOD 340nm with rainfall of July month.

days and April 4 days. In August, there was highest rainfall followed by July, June and May having a total of 471.5mm, 449mm, 95.5mm and 92mm respectively. The precipitation occurred in August for 15 days, July for 14 days, June for 4 and May for 3 days.

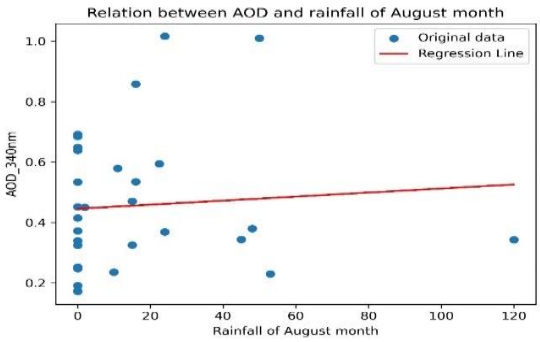

Figure 8: Correlation of AOD 340nm with rainfall of August month.

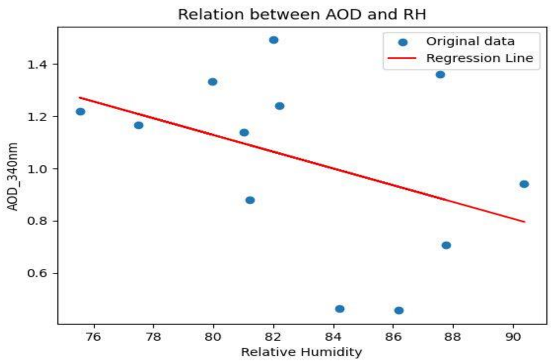

Figure 9: Correlation of AOD 340nm with relative humidity.

The correlation coefficient of AOD with rainfall for these months are 0.075, 0.241, -0.1 and -0.42 respectively. In figure 8 the correlation of AOD with relative humidity (RH) is shown and there is negative correlation between them with correlation coefficient -0.41. The highest monthly average value of relative humidity is 90.38 on the January month and the AOD value is 0.94 whereas the lowest monthly average is 75.54 on the April month and monthly average AOD of April month is 1.22.

Figure 9 shows the correlation between AOD and relative humidity for July 2018. It showed positive correlation between alpha and rainfall with correlation coefficient 0.24.

From figure 10 we can see there is strong positive correlation between angstrom exponent and relative humidity (RH). The correlation coefficient was found to be 0.713.

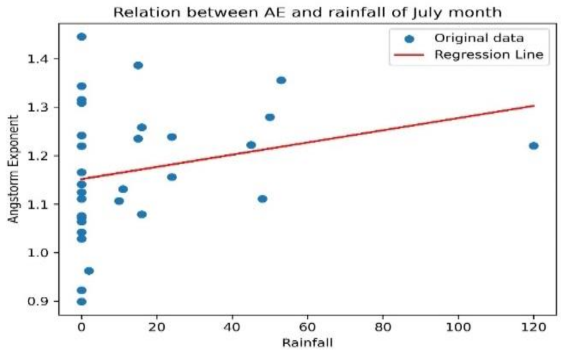

Figure 10: Correlation of angstrom exponent and rainfall of July month.

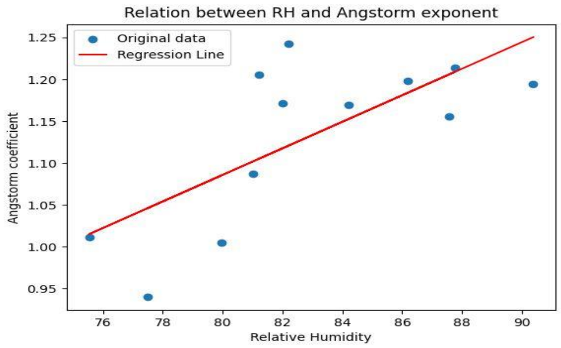

Figure 11: Correlation of angstrom exponent with relative humidity.

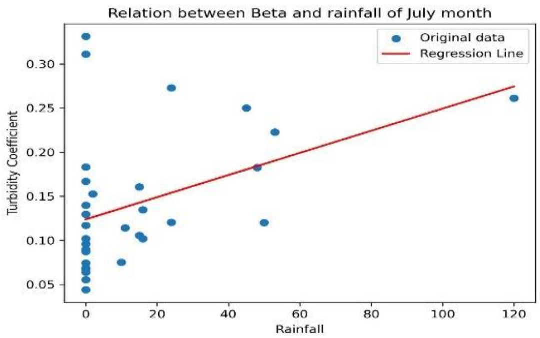

Figure 12: Correlation of turbidity coefficient with rainfall of July 2018.

In figure 11 there is positive correlation between turbidity coefficient(beta) and rainfall in the July month with correlation coefficient 0.42. From figure 12 we see there is negative correlation between beta and relative humidity(RH). The correlation coefficient was found to be -0.527.

From the graph above we see that the correlation of AOD with rainfall was varied. We didn't calculate the correlati-on of rainfall with other months except May, June, July and August, as these months have the total rainfall of less than 20mm. In May and June, we got the negative correla-tion and in July and August positive correlation was obtained. There was very much less rainfall in May and June in comparison to July and August. This shows that higher the rainfall higher will be the AOD and vice-versa. Kang et.al., (2015) also showed that AOD was highest in summer (June/July) in the west and central part of China [27] as well

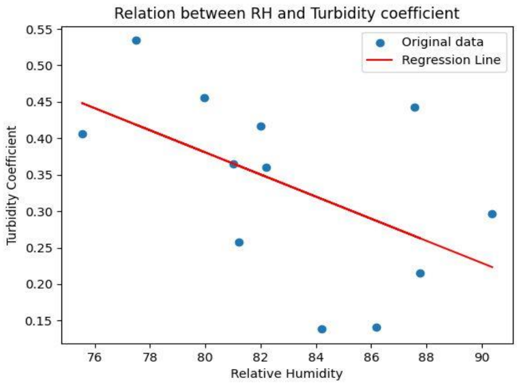

Figure 13: Correlation of turbidity coefficient with relative humidity.

as Sarthi et.al., (2019) showed that during the year 2000-2005 showed that AOD was exceptionally increasing during the monsoon rainfall [28]. Similar results were obtained by Fan et.al., (2019) and Zhang et.al., (2012) [29, 30]. The positive correlation between AOD and rainfall indicates that there is the presence of anthropogenic

Table 1: Monthly average of α and β.

Month	α	β
January	1.194	0.296
February	1.155	0.442
March	1.086	0.365
April	1.011	0.406
May	1.004	0.456
June	0.939	0.534
July	1.169	0.138
August	1.198	0.141
September	1.213	0.215
October	1.205	0.257
November	1.242	0.359
December	1.171	0.416

aerosols which comes from fossil fuel and biomass burning [31]. The relative humidity lowers the size of dry aerosols whereas in case of hygroscopic aerosols it depends on size and solubility of aerosols [32]. Prasad et.al., (2023) also found that there was inverse relationship between aerosols and relative humidity in the central India, Indo-Gangetic plain and west coast of India. Our study area Lumbini also lies in the Indo-Gangetic Plain [33].

Conclusion

In this study, the influence of meteorological parameters on aerosol optical properties over Lumbini was investigated using AOD data obtained from the CIMEL sun photometer. It was found that the aerosol particles exhibited predominantly hygroscopic behavior, with significant contributions from biomass burning, vehicular emissions, and industrial activities. A positive correlation between AOD and rainfall was observed, while a negative correlation with relative humidity was identified, indicating that aerosol size tended to increase with moisture availability.

The analysis of the Angstrom exponent suggested the presence of relatively larger particles during certain periods, particularly during June, when high turbidity conditions were recorded. However, it must be acknowledged that limitations such as the lack of temperature and wind speed data constrained a more comprehensive understanding of aerosol behavior.

Although only one year of data (2018) was analyzed, valuable baseline information was established regarding aerosol variability in a climatically and culturally significant region. It is recommended that future studies incorporate multi-year datasets, back-trajectory analysis, and aerosol-chemistry modeling (e.g., HYSPLIT, GEOS-Chem) to strengthen source attribution and to validate observational findings. Enhanced understanding of aerosol characteristics over regions like Lumbini is essential for informing air quality management policies and assessing climatic impacts within the Indo-Gangetic Plain.

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